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PROPELLER TESTS ON AIRPLANES.

By A. Senouque.

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At first thought, it would appear easy to compare two propellers and choose the more suitable one for a given airplane, by simply determining the revolution speed of each propeller with the throttle wide open and then choosing the one with the highest speed. Any choice made in this manner can only be considered as a first approximation, for, although this test shows which propeller will give the airplane the greatest speed, it gives us no information regarding its efficiency and does not prove in advance but that the slower propeller, after being modified, might drive the airplane faster than the other.

In order to determine the efficiency of a propeller as accurately as possible, its revolution speed, thrust and power absorbed must be measured during flight. Unfortunately, these measurements can be made only by experienced persons and with very complicated apparatus. Since at the present time, constructors can hardly retain an airplane long enough for the installation of very fragile and expensive instruments, we thought it would be better to content ourselves with approximate results obtainable in two or three hours of flight, with only the instruments ordinarily employed in the acceptance tests of military airplanes. These tests can be made by any pilot and no special instruments are required. We tried several experiments of this kind at the

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Buc airdrome on an F.50 airplane, with two Lorraine 275 HP engines. Although these tests were incomplete, we will give a detailed account of them.

We had the following instruments on board:

1. A Badin speed indicator, which we had adjusted in calm weather while flying at an altitude of about 30 meters above a straight road of 4600 meters;

2. An altimeter registering from 0 to 500 meters, with a cylinder revolving once in 30 minutes;

3. Tachometers giving the revolution speeds of the engines.

We also had the curve of the engine tests on the bench.

There were two series of flights to be made: climbing and horizontal. These flights naturally had to be made in calm weather.

Climbing flights were made with wide-open throttles. During each climb, the speed of the airplane was kept constant by watching the Badin anemometer dial and keeping its pointer always on the same division, which was easily done. The test began when the airplane was about 20 meters from the ground. On reaching an altitude of 500 meters, a gliding descent was made and, without landing, another climb was begun at a different speed from the first. During each test the revolution speeds of the propeller were noted, as given by the tachometers. In this manner, five or six tests were made at different speeds nearly uniformly distributed between the highest and lowest speeds possible in safety. In these tests the speed of the airplane in its trajectory was given by the Badin anemometer and its vertical speed was calculated from measurements made on the curves of the recording altimeter. Care had simply to be taken to utilize these curves only between 100 and 450 meters, since, outside these limits, the climbing speed could not be kept uniform, because of the accelerations produced at the moment of changing the direction of flight.

The horizontal flights were made at an altitude of about 30 meters, this altitude being maintained by estimating with the eye. If it were desired to operate at a much higher altitude, it would be necessary to use a very sensitive altimeter, whose pointer would move at least 2 mm. for a difference of 10 meters in altitude, and to keep the pointer always on the same mark. The flight is begun with throttles wide open for at least two minutes, while continually watching the Badin anemometer and the tachometers, in order to determine the average speed of the airplane and the revolution speed of the propellers. When this article was written, other tests were being made with throttled engines and diminished speeds. As in the climbing flights, five or six tests were made at speeds distributed uniformly between the highest and lowest horizontal speeds attainable.

We have only been able to test propellers of two different types. The first were Chauvière propellers habitually mounted on F.50 airplanes. The others (No.2) were made according to our own specifications. These propellers, of 2.8 meters diameter, only differed in pitch, No. 1 having a pitch of 1.6 meters, and No. 2

having a pitch of 3.2 meters. The results of our experiments are given in the following tables. Table I relates to climbing tests and Table II to horizontal flights.

TABLE I.

Propellers No. 1 (Chauvière)						Propellers No. 2.					
V	v	N	n	$\frac{V}{n}$	P	V	v	N	n	$\frac{V}{n}$	P
ms	ms				HP	ms	ms				HP
43.6	0.00	1720	28.6	1.52	540	41.6	0.00	1510	25.2	1.65	492
37.2	0.57	1700	28.3	1.31	536	37.2	1.63	1490	24.8	1.49	484
34.4	2.78	1680	28.0	1.23	534	34.4	2.78	1470	24.5	1.40	476
31.2	3.91	1660	27.7	1.13	526	31.2	3.00	1450	24.2	1.29	468
27.4	4.44	1630	27.2	1.01	520	27.4	3.56	1430	23.8	1.20	460
23.7	4.30	1610	26.8	0.89	516	23.7	3.30	1410	23.5	1.05	452

TABLE II

Propellers No. 1 (Chauvière)					Propellers No. 2.				
V	N	n	$\frac{V}{n}$	P	V	N	n	$\frac{V}{n}$	P
ms				HP	ms				HP
43.6	1720	28.6	1.52	540	41.6	1510	25.2	1.65	492
36.3	1500	15.0	1.45	356	35.4	1300	21.7	1.63	314
30.4	1300	21.7	1.41	236	31.8	1200	20.0	1.59	244
27.0	1200	20.0	1.35	182	27.8	1100	18.3	1.52	188

In these tables, V is the horizontal speed of the airplane, v its vertical speed, N the r.p.m., and n the r.p.sec. of the propellers, V/n the advance per revolution and P the energy expended. Since, in the horizontal flights, the engines did not always run with throttles wide open, we cannot read directly on the curve of the engine tests the power absorbed by the propellers. In order to find it, we must make a calculation which presents no difficulty, if we assume that, for the same advance per revolution, the power absorbed is proportional to the cube of the number of revolutions. Let us find, for example, the power generated by the engines when propellers No. 1 revolve at 1300 r.p.m. and the advance per revolution is 1.41 meters. In Table I, we see that between an advance of 1.31 meters per revolution and one of 1.52 meters, the power and number of revolutions vary but little. We may therefore assume that, between these two forward speeds of the propellers, these values are proportional to the advance per revolution. We will then have, for an advance of 1.41, N = 1710 and P = 538.

The power absorbed at 1300 r.p.m. will then be

$$P = 538\left(\frac{1300}{1710}\right)^3 = 236\ \text{HP}$$

From the results in the preceding tables, we traced the graphics in Figs. 1-3. The first, made from the data in Table I, gives for each propeller type the variations in the vertical speed of the airplane in terms of its horizontal speed. On each curve we have written the power absorbed by the propellers. The second graphic gives the variations in the power absorbed during the horizontal flights and climbs in terms of the horizontal speed of the airplane. On these curves we have indicated the advance per revolution of the propellers. The M curves were taken from Table II and give the variations of the power expended, when the engines worked with throttles wide open during the climbs. The H curves represent the variations of the power expended when the engines worked with reduced intake in horizontal flight.

If we examine the curves of Fig. 1, without taking account of the power absorbed, we shall conclude immediately that the No. 1 propellers are preferable to the others because, with throttles wide open, they give a greater horizontal speed (43.6 instead of 41.6 m/s) and also because the climbing speed is greater (4.44 instead of 3.6 m/s). But, if we take account of the power absorbed, our conclusions will no longer be the same. In fact, we see that both curves have a common point A. This indicates that at that instant both types of propellers are capable of giving the airplane the same horizontal and vertical speed. Hence they furnish the same amount of useful energy. But, on the other hand, we see by regarding the values of the powers inscribed on the curves, that the No. 1 propellers absorb, under these conditions, 536 HP, while propellers No. 2 absorb only 490 HP, a difference of 46 HP, or 9%, which is not negligible.

Let us now pass to the curves of Fig. 2. At the point B, corresponding to a horizontal speed of 41.5 m/s, both the H curves intersect. Hence the propellers absorb the same power and, since they give the airplane the same horizontal speed, they furnish the same useful energy and have therefore the same efficiency. If we now examine what takes place when the speed of the airplane is 35 m/s, we see that with propellers No. 1 the engines must give 335 HP, while with propellers No. 2 they will give only 305 HP. The difference is 30 HP. Hence, by using the latter, we would make a saving of 10% in the power expended.

In short, if, in the utilization of the airplane, we can be satisfied with a vertical speed of 3.6 m/s instead of 4.44 m/s and with a maximum horizontal speed of 41.6 m/s (150 km/h) instead of 43.6 m/s (157 km/h), which is entirely inadmissible in air traffic, we will adopt the No. 2 propellers. In fact, at all the attainable speeds up to 41.6 m/s, the No. 2 propellers require less power for the same horizontal speed. There will be, therefore, an appreciable saving of fuel and a considerable diminution of engine fatigue and if, in exceptional instances, we are obliged to fly with the maximum power of the engines, the difference in the speeds attained will make only a very slight difference in the duration of the flight. Thus a flight of 300 km. (about the distance from Paris to Brussels) would take two hours with propellers No. 2 and six minutes less with the others. The No. 2 propellers have the disadvantage of braking the engines too much, which can hardly be utilized beyond 245 HP, although their maximum power is 275 HP. This may sometimes interfere with starting from bad fields. Therefore, in order to utilize all the engine power in taking off the diameter of propellers No. 2 would need to be diminished so they can revolve more rapidly, but we do not yet have all the data necessary for calculating this diameter.

We did not have time to continue these tests, which enable us under certain flight conditions to compare the efficiency of the propellers, but which cannot give the absolute value of the output, nor especially the variations in this output. Since our experiments have only given us the energy dispensed, we need to supplement them by determining the useful energy.

Fortunately this determination can be readily made after each climb. After reaching the altitude fixed for these flights, we descend with the engines at their lowest speeds and with the pointer of the Badin anemometer on the same division of its dial, which keeps the speed of the airplane constant, its path will be an inclined straight line and its descending speed will be given, like its climbing speed, by the curves of the recording altimeter. Thus we make several descents at different speeds and we have all the data necessary for calculating the variations of the power utilized. Since the propellers revolve at a low speed, they exert only a very feeble pull in the direction the airplane is moving, or in the opposite direction, which we may neglect. The airplane is then subject only to the influence of the weight, while the power utilized will equal the product of the weight of the airplane times the vertical speed. Thus, when the airplane (which weighs 2550 kg.) descends in a glide with a speed of 38 m/s in its trajectory and with a vertical speed of 8.15 m/s, the power utilized, P_u, will be

$$P_u = 2550 \times 8.15 = 20800 \text{ kg/m/s} = 277 \text{ HP.}$$

We will make the same calculations for the other speeds of gliding descent and we have all the data necessary for tracing in Fig. 2 the curve P_u of the useful powers in terms of the speeds. Since the gliding descents, up to a speed of 45 m/s, are made at a small incline, we have again assumed that, for a given speed, the power utilized was the same in gliding as in horizontal flight.

We now have, for the different speeds of the airplane in horizontal flight, the power P expended at the same time as that of the useful power P_u and we can deduce from it the efficiency η of the propellers. Thus, when the airplane flies horizontally at a speed of 38 m/s, the No. 2 propellers will have an efficiency

$$\eta = \frac{P_u}{P} = \frac{277}{375} = 0.74$$

The propeller efficiency while climbing is not found so easily. In this case and for a given speed, the power utilized equals the power in horizontal flight increased by the product of the weight of the airplane times its vertical speed. Thus, when the airplane has a speed of 28 m/s and when it climbs at the rate of 3.56 m/s. we will have, according to graphics 1 and 2:

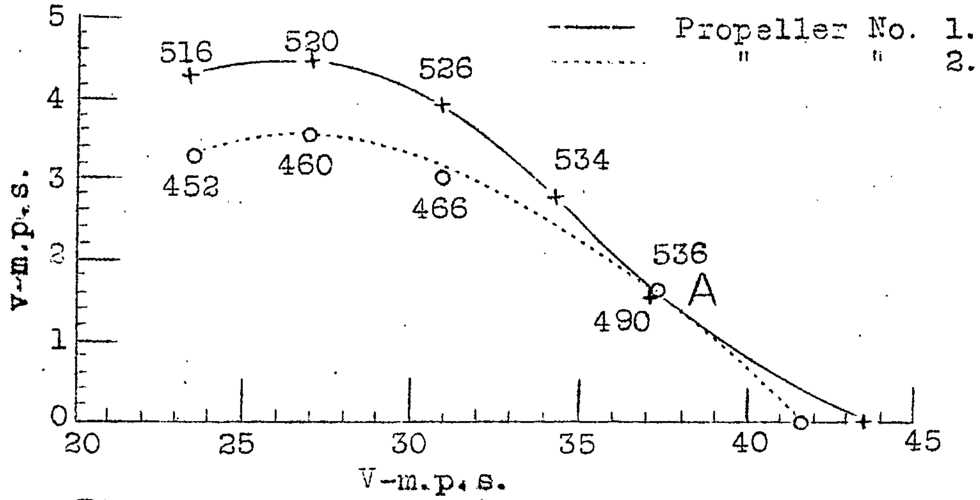
$$\eta = \frac{263}{450} = 0.583$$

It is desirable to follow the variations in the efficiency of the propellers, not in terms of the speed of the airplane, but in terms of their advance per revolution, or, better still, according to the ratio V/D_n, in which V is the translation speed of the propeller, which is equal to the speed of the airplane in its trajectory, n the number of r.p.sec. of the propeller, and D, its diameter. We give therefore (Fig. 3) the curve of the variations of the efficiency of the No. 2 propellers in terms of V/D_n.

With all these data we can compute the coefficients α and β of Revard, as also the curves of the useful powers in terms of the propeller speeds more or less high, but similar to the No. 2 propeller, and determine which one is better adapted to our airplane and to its engines.

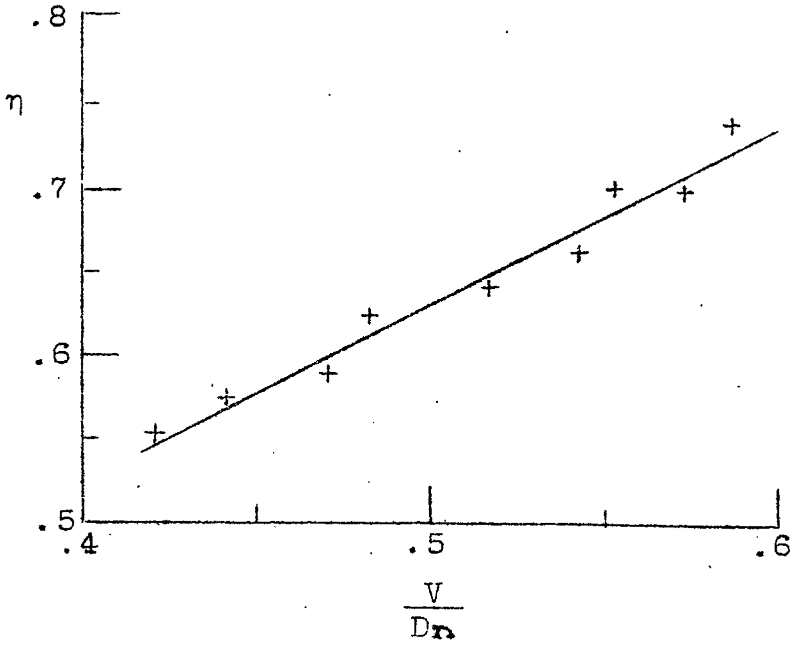
Aside from these propeller questions, the curves which correspond to the powers with reduced intake show us that the horizontal speed limit is practically 28 m/s with an expenditure of only 200 HP and that, at this instant, the power has not yet reached its minimum. The airplane, as it is, cannot fly therefore at its minimum power, for at this speed its controls would not be effective. It would therefore be advantageous to increase the area of the control surfaces, in order to enable it to fly at the speed of its minimum power and, above all, to land more gently.

Translated by the National Advisory Committee for Aeronautics.



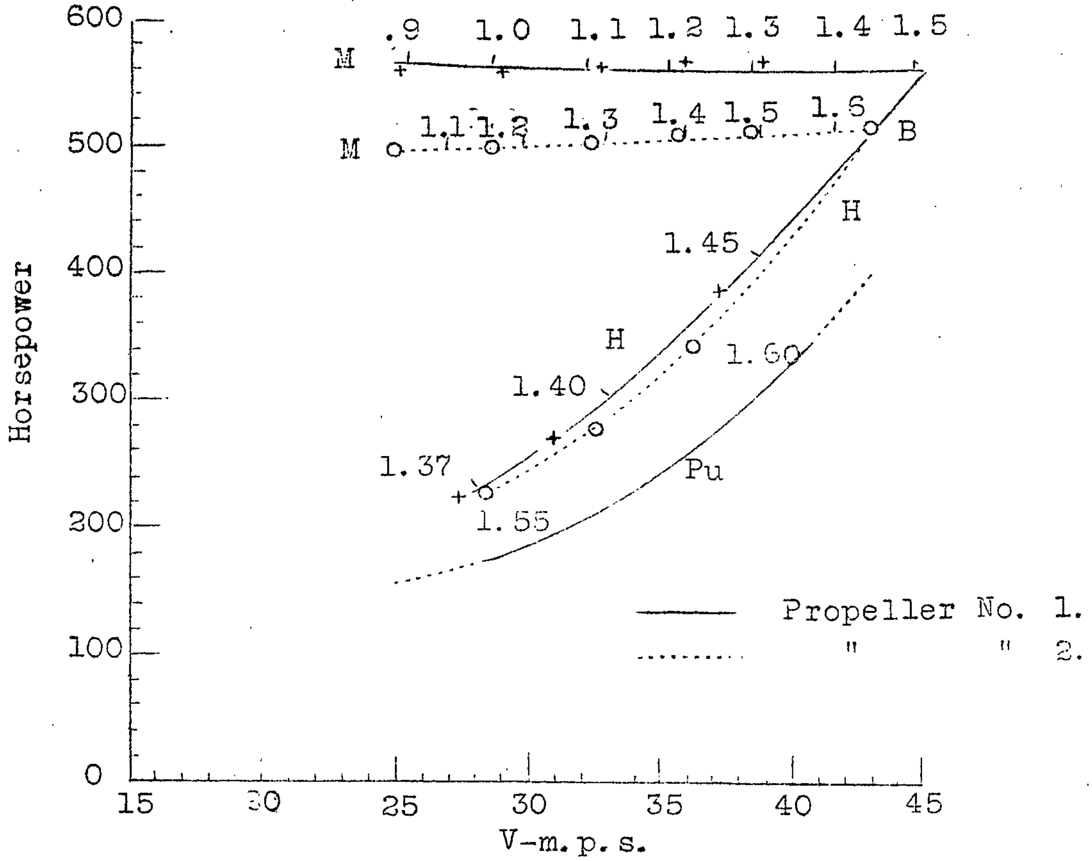
Propeller No. 1.
" " 2.
516
520
526
534
536
A
490
452
460
466
v-m.p.s.
V-m.p.s.
0
1
2
3
4
5
20
25
30
35
40
45

Fig. 1.



η
.5
.6
.7
.8
.4
.5
.6
V
Dn

Fig. 3.



600
500
400
300
200
100
0
Horsepower
.9 1.0 1.1 1.2 1.3 1.4 1.5
M
1.1 1.2 1.3 1.4 1.5 1.6
M
B
H
1.45
H
1.40
1.60
1.37
Pu
1.55
Propeller No. 1.
" " 2.
15 20 25 30 35 40 45
V-m.p.s.

Fig. 2.